National Aeronautics and
Space Administration
Office of the Administrator
Washington, DC 20546-0001

January 12, 2015

Dr. Steven W. Squyres
Chairman
NASA Advisory Council
Washington, DC 20546

Dear Dr. Squyres:

Enclosed are NASA's responses to two recommendations from the NASA Advisory Council meeting held on July 30-31, 2014, at the NASA Langley Research Center. Please do not hesitate to contact me if the Council would like further background on these responses. I appreciate the Council's thoughtful consideration leading to the recommendations and welcome its continued findings, recommendations, and advice concerning the U.S. civil space program.

I look forward to working closely with you and members of the Council in the future.

Sincerely,

Charles F. Bolden, Jr.
Administrator

2 Enclosures:
2014-02-01 (Council-01) Mismatch Between NASA's Aspirations for Human Space Flight and Its Budget
2014-02-02 (Council-02) Asteroid Redirect Mission

NASA Advisory Council Recommendation

Mismatch Between NASA's Aspirations for Human Space Flight and Its Budget 2014-02-01 (Council-01)

Recommendation:
The mismatch between NASA's aspirations for human spaceflight and its budget for human spaceflight is the most serious problem facing the Agency. NASA should carefully consider what steps would have to be taken in the years ahead in order to meet the national goal of sending humans to Mars in the 2030s with a realistic budget. The Agency should be prepared to articulate these steps publicly.

Using the best available information for Humans to Mars selected from the past 40+ years of studies, NASA should identify the "minimum path" of only those technologies and capabilities absolutely required, and perform internal and independent cost estimates of this minimum path. The result should be compared to a notional 25-year budget that only grows with inflation. The resultant shortfall should be used to address what combination of budget increase, added partnerships, and/or adjustments to NASA portfolio scope would be necessary to attain the goal.

Addressing this important issue will be an ongoing process. We request that the Agency brief us regarding the implementation of this recommendation at our next meeting, and at subsequent ones.

Major Reasons for Proposing the Recommendation:
The Council agrees with the recent National Research Council (NRC) report on pathways for human exploration[1] that sending humans to Mars is an appropriate "horizon goal" for NASA. We also agree with the report's conclusion that a budget that does not grow above inflation will never allow that horizon goal to be achieved. The only ways to address this mismatch are to: (1) increase the NASA budget over projections; (2) adjust NASA's portfolio of activities; (3) offset costs with new efficiencies and/or contributions by outside partners; or (4) adopt a different horizon goal for the Agency.

Consequences of No Action on the Proposed Recommendation:
If this fundamental mismatch is not addressed in a serious way, the Agency runs the risk of squandering precious national resources on a laudable but unachievable goal.

---

[1] *Pathways to Exploration – Rationales and Approaches for a U.S. Program of Human Space Exploration, National Research Council, 2014.*

NASA Response:
NASA partially concurs. NASA agrees we should carefully consider what steps would have to be taken in the years ahead in order to meet the national goal of sending humans to the Mars vicinity in the 2030s with a realistic budget. Further, we agree the Agency should be prepared to articulate these steps publicly.

Enclosure 1

NASA recognizes the need to advance the capabilities required to extend human presence into the solar system and eventually to Mars within a budget that grows only modestly over present levels. International and commercial partnerships are emerging in many areas as space capabilities diffuse and grow domestically and around the world. This offers opportunities that will continue to evolve over time and that can be leveraged. These capabilities would otherwise have to be provided by NASA. This more capabilities-based approach to our exploration strategy implementation means that we will hold open more architecture decisions while these external opportunities can be assessed, negotiated, and in some cases matured and subsequently added. This, coupled with the inherent difficulty with forecasting availability dates for selected technologies, makes it challenging to lay out and cost a minimum path to Mars. But we are, in parallel, actively assessing existing design reference approaches and identifying the figures of merit and alternate approaches that will lead to affordable and sustainable exploration systems.

We have identified the key capabilities that must be matured in order to enable future exploration. These encompass the technologies identified by the NRC and align well with those identified in NASA's Technology Roadmaps. System Maturation Teams made up of experts across NASA Centers and programs comprise these teams. In each area, they are identifying what capabilities can be advanced using the International Space Station (ISS), using Asteroid Redirect Mission (ARM) and other Space Launch System (SLS)/Orion missions in the Proving Ground of cis-lunar space, and using robotic precursor missions to Mars' orbit, moons, and surface.

Under the framework of the Evolvable Mars Campaign we introduced to the NASA Advisory Council (NAC) in June 2014, NASA is studying a split mission Mars approach that utilizes both chemical and advanced solar electric propulsion to provide a sustainable path with technologies and capabilities absolutely required for crewed missions to the Mars vicinity and Mars surface. This links to and informs studies of optimal pre-positioning of assets in cis-lunar space and Mars orbit, as well as optimal Mars surface lander sizes and other capability needs to guide technology investments. We will brief the early results of this work to the NAC in January 2015. But much additional work needs to be done over time as stated above in order to show that we have an architecture that can be accomplished both technically and programmatically, including within reasonable assumptions of future budget availability.

The series of human exploration missions NASA is planning in the Proving Ground follow this resilient and evolving approach for human exploration of the solar system. NASA is defining mission objectives of Exploration Mission-1 (EM-1) and Exploration Mission-2 (EM-2) to demonstrate the utility of lunar orbits to enable energy-efficient transfers of large masses to Mars, to conduct cis-lunar space operations we will have to master to exploit them, and to test technologies and reduce risk for the next missions. We are also using the System Maturation Team (SMT) and Evolvable Mars Campaign results to identify the set of objectives that should be accomplished in the Proving Ground over the first 5-10 years of EM flights, including the crewed mission to the asteroid redirected there by ARM.

NASA's reference plan is for this crewed mission to encompass 26-28 days, including 5 days in the stable lunar distant retrograde orbit for Orion rendezvous and docking with the ARM robotic spacecraft and attached asteroid mass, and implementing the astronauts' Extra-Vehicular Activity (EVA). There are many aspects of this crewed mission in the mid-2020's that will build capabilities and reduce risk for Mars missions such as: Moving large objects through interplanetary space using solar electric propulsion (SEP); integrated crewed/robotic vehicle stack operations in deep space orbits, e.g., integrated attitude control, solar alignment and during multi-hour EVAs; lean implementation of SEP vehicle builds using clean interfaces, streamlined processes, and common Autonomous Rendezvous and Docking (AR&D) systems; and broad scope robotic/crewed integration, including crewed system hardware deliveries to and integration and test with robotic spacecraft, and joint robotic spacecraft and crewed mission operations.

In parallel with human exploration missions in the Proving Ground, NASA is continuing its strategy of using robotic missions to advance technology and close strategic gaps in knowledge about the Martian environment that will be critical for designing future human exploration systems. The Curiosity rover continues to monitor the radiation and weather environment on the surface of Mars, and in late July 2014, NASA announced that one of the seven instruments selected for the Mars 2020 rover mission would be an exploration technology investigation that would produce oxygen from the plentiful carbon dioxide in the Martian atmosphere. If demonstrated successfully and done on a larger scale in the future, such a system could make oxygen for rocket fuel or for astronauts to breathe. Another selected instrument on Mars 2020 will provide measurements of temperature, wind speed and direction, pressure, relative humidity and dust size and shape. Understanding the Martian weather and dust characteristics will be valuable data for planning human Mars missions. In addition, Mars 2020 will include sensors on the heatshield and aeroshell to collect data during entry, descent and landing, as was done on the Mars Science Laboratory mission. The data collected will help mission planners design future landing systems human exploration. Improved navigation technologies are also being considered for the proposed Mars 2020 rover that could improve the ability of future missions related to human exploration – which likely would involve multiple payloads – to land close together.

As NASA extends human presence into the solar system and eventually to Mars in the years ahead, additional work is being defined and mission options are being developed. Mission options under study include further use of the advanced solar electric propulsion bus used for ARM; addition of a deep space habitat; additional return missions to the asteroid for expanded science and/or resource utilization; support for commercial and/or international missions in the lunar vicinity; and/or new missions to Mars vicinity that accomplish science, technology, and human exploration objectives. The past 6-12 months of work has identified options and phasing of capabilities that we had not predicted earlier, and we expect our ongoing studies to do more of the same. Over the next months and years, we will continue to define and evolve the set of missions and capability developments that accomplish the most forward progress and advance key capabilities taking close account of expected resources. In so doing, we will follow the strategic principles for exploration we discussed with the NAC in June 2014. We look forward to working with the NAC in its subsequent meetings, and discussing the findings of our architecture studies as they emerge.

NASA Advisory Council Recommendation

Asteroid Redirect Mission
2014-02-02 (Council-02)

Recommendation:
The Council recommends that NASA should conduct an independent cost and technical assessment of the Asteroid Redirect Mission (ARM). NASA should state clearly in advance what the cost and technical criteria are for implementing the mission. These criteria should include affordability within currently projected budgets. The independent assessment should be performed before the downselect between Options A and B. The possible outcomes of this process are: fly Option A, fly Option B, or (if the projected cost is unacceptable) fly neither.

Major Reasons for Proposing the Recommendation:
NASA's current Asteroid Initiative has three elements: (1) the search for and identification of Near Earth Asteroid (NEA) targets; (2) redirection of one NEA target to near-lunar orbit; (3) astronaut crew to cis-lunar space to rendezvous with the target and conduct operations. The cost of the second element (asteroid redirect, e.g., ARM) is poorly defined at present. The other elements of the Asteroid Initiative (target search and flights to cis-lunar space) still have merit even if the redirect mission does not take place. It must also be noted that ARM is not a substitute for a mission to an asteroid in its native orbit, which appears to be possible at a lower launch energy than previously believed based on recent data[2-4]. Such a long duration deep space mission would be a logical step toward the horizon goal of humans to Mars. We have concerns that the ARM mission as currently defined may pose an unacceptable cost and technical risk. A prudent response to such concerns is to conduct and independent cost and technical assessment prior to selection.

Consequences of No Action on the Proposed Recommendation:
A mission of significant cost and technical risk may be implemented without a full understanding of the potential for significant cost overrun or schedule slip.

NASA Response:
NASA concurs that it is important to conduct an independent cost and technical assessment prior to selection of an Asteroid Redirect Mission (ARM) concept. Cost is a key consideration, and the selection decision will also consider other aspects, such as cost risk and the extensibility of the mission concept to future NASA exploration missions. NASA's Mission Concept Review (MCR) is planned for early 2015, and will include an independent NASA technical and cost assessment for the selected mission concept.

To narrow the trade space for the MCR, a robotic mission capture option down-select review was conducted in December 2014, with a decision expected in January 2015. Our use of 'Option A' and 'Option B' describes whether we will redirect a small asteroid from its native orbit or retrieve a boulder from a larger asteroid. In addition to internal NASA concept development, we have awarded 18 six-month study contracts with industry to better inform both the mission concept down-selection and the MCR. Cost projections and development schedules are generally included in these contract deliverables.

The interim reports will be available prior to the mission concept down-selection. The ARM team is refining a detailed cost estimate for both internal capture concept options A and B, which includes a grass-roots estimate of the projected costs for both options. An independent NASA team, using experienced project managers and a combined team of experienced Jet Propulsion Laboratory and Goddard Space Flight Center cost analysts, will assess each cost basis of estimate in support of the down-select.

In the MCR, a mission concept for the selected capture option will be reviewed. Final reports from the Broad Agency Announcements contracts will be included in the proposed mission concept, as well as an independent NASA cost assessment by this same cost analyst team. Given NASA's approach to leveraging ongoing work and the current state of integrated mission definition, we will review the proposed mission concept at MCR and set constraints for design and long lead acquisitions, including mission cost, launch readiness date, risk management approach, descope options, and cost and schedule reserves.

While recent analyses indicate the possibility of astronauts visiting an asteroid in its native orbit at delta velocities on the order of 5 km/s from low Earth orbit (LEO), similar to the ARM Crewed Mission, these candidate asteroids still yield transit times from LEO of over 3.5 months[1]. Shorter missions, of the order of 70 days, may be possible at delta-Vs of around 7 km/s[1]. NASA's reference plan for the ARM crewed mission encompasses a 26-28 day mission, including 5 days in a stable lunar distant retrograde orbit, which is within the capabilities of the Block I SLS/Orion vehicles. ARM can be accomplished prior to the availability of additional capabilities such as longer duration life support. In addition, this beyond LEO mission offers drivers for lower mission risk posture such as early crew and Orion auxiliary thruster contingency returns, including within consumables limits. This makes ARM a more logical early step beyond LEO toward the horizon goal of humans to Mars.

Many other aspects of ARM build capabilities and reduce risk for Mars missions, including:

- Moving large objects through interplanetary space using solar electric propulsion (SEP);
- Integrated crewed/robotic vehicle stack operations in deep space orbits (e.g., integrated attitude control, solar alignment during multi-hour EVAs);
- In-space systems for astronaut extra-vehicular activity;
- Sample selection, handling, and containment;
- Lean implementation of an upgradable deep space operational SEP vehicle; and
- Broad scoped robotic/crewed integration, including crewed system hardware deliveries to and integration and test with robotic spacecraft, and joint robotic spacecraft and crewed mission operations.

Our early 'Proving Ground' missions provide systems and technology testing and operational experience beyond the "Earth Dependent" domain of the International Space Station (ISS). Risk reduction in the Proving Ground, with returns to Earth possible within a few days, complements the important long duration human system risk reduction on the ISS. As presented in the sustainable exploration 'split mission' Mars approach, NASA missions in the Proving Ground will use both chemical propulsion based human transportation systems and high power, long life solar electric propulsion systems as a sustainable path in collaboration with international and commercial partnerships.

Cis-lunar space missions are necessary for risk reduction prior to visiting an asteroid in its native orbit. ARM provides significant contributions in the Proving Ground for future human missions to Mars. ARM also offers an opportunity for interesting science, for less cost and risk, than a crewed visit to an asteroid in its native orbit.

---

[1] Regarding the assumptions, as written on the Near-Earth Object Human Space Flight Accessible Targets Study (NHATS) home page at <http://neo.jpl.nasa.gov/nhats/>: "*The list of potential mission targets should not be interpreted as a complete list of viable NEAs for an actual human exploration mission. As the NEA orbits are updated, the viable mission targets and their mission parameters will change. To select an actual target and mission scenario, additional constraints must be applied including astronaut health and safety considerations, human space flight architecture elements, their performances and readiness, the physical nature of the target NEA, and mission schedule constraints.*"